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# Experimental digital transmission of multiplexed video and audio signals at 120 Mbit/s

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# EXPERIMENTAL DIGITAL TRANSMISSION OF MULTIPLEXED VIDEO AND AUDIO SIGNALS AT 120 MBIT/S

**D.W. Osborne, C.Eng., M.I.E.E.**

## Summary

*During 1975, field trials were carried out in which 120 Mbit/s signals, generated by equipment specially constructed in BBC Research Department, were transmitted over a UK Post Office experimental high-speed digital line system. Multiplexed video and audio signals were sent from Portsmouth to Guildford and back, from Portsmouth to Southampton and back, and also through both of these circuits in tandem. An outline of the experimental equipment is given. No serious difficulties arose in the trials but several interesting facts which emerged are discussed, mainly concerning error performance and timing jitter.*

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BRITISH BROADCASTING CORPORATION

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The corrections appear to be in the late author’s own hand.

John Barrett 10th October 2005.

# EXPERIMENTAL DIGITAL TRANSMISSION OF MULTIPLEXED VIDEO AND AUDIO SIGNALS AT 120 MBIT/S

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# EXPERIMENTAL DIGITAL TRANSMISSION OF MULTIPLEXED VIDEO AND AUDIO SIGNALS AT 120 MBIT/S

D.W. Osborne, C.Eng., M.I.E.E.

## 1. Introduction

Broadcast-quality sound-programme signals have been distributed in digital form from the studios to many transmitters in the BBC networks for several years and the advantages expected, particularly for stereophony, from this form of transmission have been confirmed. Advantages would also be expected for the digital transmission of video signals, which is likely to be used ultimately when suitable bearer circuits become available. For a number of years therefore the BBC has been investigating the coding parameters required for broadcast-quality video signals and investigations are continuing on techniques for reducing the bit rate of both video and audio signals as well as for error protection.

In 1975 an Experimental Digital Line System, operating at 120 Mbit/s and providing two-way circuits linking Southampton, Portsmouth and Guildford, was commissioned for the United Kingdom Post Office (UK PO). Following an invitation by the Post Office to participate in field trials in 1975, the BBC provided multiplexed video and audio broadcast-quality signals for transmission over the experimental circuits. This enabled the BBC to gain experience in the design and construction of a high-speed multiplex equipment and in using a high bit-rate cable transmission system. The tests were also of considerable interest to the Post Office and to the manufacturers involved in the line-system equipment since previous tests had used fixed patterns and pseudo-random-sequence data signals unlike the coherent data signals of the BBC transmissions.

This report gives a brief outline of the digital line system before indicating the source-coding systems and multiplexing techniques used in the BBC equipment. It then presents some of the more important results of the UK PO/BBC field trials.

## 2. The 120 Mbit/s transmission system

The digital signal is carried on a 1·2/4·4 mm coaxial cable with regenerative repeaters spaced at intervals of about 2 km. There are 36 repeaters in each direction of transmission on the Portsmouth/Guildford section and 17 repeaters in each direction of transmission on the Portsmouth/Southampton section, the equipment being built to a basic Post Office specification.* The customer interface code with the terminal equipment is HDB-3.[1] This is first translated to binary and then to a ternary line code for actual transmission over the circuit, with the reverse process at the receiving terminal.

The Portsmouth/Guildford line code is 4B3T,[1] and a feed-back scrambler and complementary feed-forward descrambler are normally included in the system where the signal is in binary form. The Portsmouth/Southampton line transmission code is MS43[1] with no built-in provision for scrambling. However, external equipment was available for investigating the effect of scrambling the transmitted signal. A jitter reducer was optionally available in each of the two systems.

The BBC equipment was installed at the Portsmouth terminal for the field trials thus enabling test transmissions to be made over the Guildford loop, the Southampton loop and through the two loops connected in tandem. The 4B3T signal was looped at Guildford, (i.e. the loop circuit was equivalent to a continuous path containing 72 repeaters). At Southampton the HDB-3 signal was looped, (i.e. the signal passed through the whole of the terminal equipment) and a total of 34 repeaters was included in the transmission path.

## 3. The BBC 120 Mbit/s signal

### 3.1. General

Two sets of experimental equipment were produced by BBC Research Department, one for pilot field trials in April 1975, and another, more complex equipment, for the main field trials made in October 1975. This report will be chiefly concerned with the equipment and the tests of the main field trial.

For the pilot field trial a single video pulse-code modulation (p.c.m.) signal was produced by sampling a system I PAL signal at $3 \times f_{sc}$* and linearly coding to 8-bit accuracy. A ninth parity bit was added to each 8-bit sample word, and appropriate justification was added to bring the resultant 119·7 Mbit/s rate up to the specified value of 120 Mbit/s ±15 parts per million for the system.

For the main field trial the 120 Mbit/s signal was formed from two bit-interleaved 60 Mbit/s signals designated channels A and B as shown in Fig. 1, which is a block diagram of the sender. The equipment was designed so that 60 Mbit/s signals could be made available separately if required for possible future experiments.

Each 60 Mbit/s signal consisted of a multiplex of one

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* The Portsmouth/Guildford system was provided by Standard Telephones and Cables Ltd., the terminal equipment for the Portsmouth/Southampton system was provided by GEC Telecommunications Ltd., and the regenerators were provided by Plessey Telecommunications Research Ltd.

* $f_{sc}$ = colour subcarrier frequency = 4·43361875 MHz for the 625-line PAL systems.

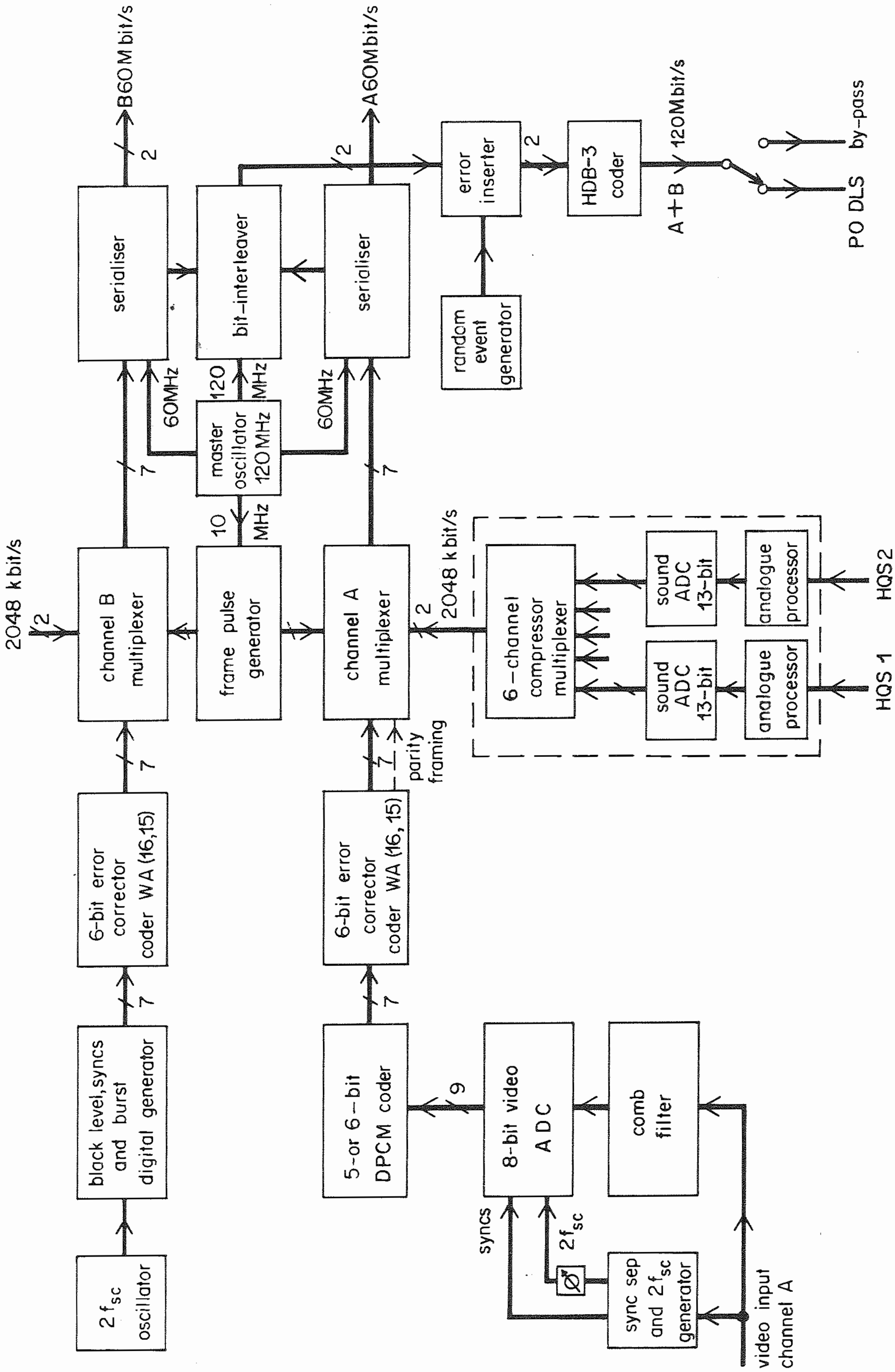

*Fig. 1 - 120 Mbit/s sender*

video signal having a nominal bit rate of 53·2 Mbit/s, and one sound-multiplex signal having a nominal bit rate of 2048 kbit/s. These two signals were asynchronous, i.e. their bit rates were independent of each other and also independent of the bit rate of the resultant 60 Mbit/s signal. Moreover, the digital video and audio signals in channels A and B comprising the 120 Mbit/s signal were also asynchronous, i.e. all four bit rates were independent of each other.

### 3.2. Video coding

Each video signal consisted of 6-bit words at a sub-Nyquist[2] sampling rate of precisely twice the subcarrier frequency of the PAL colour input signal, (nominally 2 x 4·43361875 MHz) with error-correction coding applied to each bit of the 6-bit words. The A-channel was fully instrumented, i.e. it could accept an analogue signal and code it optionally to 6-bit p.c.m., 6-bit d.p.c.m. (differential pulse-code modulation) or 6-bit h.d.p.c.m.* (hybrid d.p.c.m.) form. The equivalent serial bit rate of these signals is 53·2 Mbit/s (without error correction). A further option was available in which the signal was sent in 5-bit, h.d.p.c.m. form, the equivalent serial bit rate then being 44·3 Mbit/s; in this case the sixth bit was still present but was unused. The complementary functions of decoding, together with error correction, to provide an output analogue signal from the A-channel were fully instrumented in the receiver.

The B-channel was fed with a digitally-generated, black-level, syncs and colour burst 6-bit p.c.m. signal. This signal could be checked at the receiver by using the error-corrector and appropriate video decoding units normally used for the A-channel. As stated previously, the video signal sampling rates in channels A and B could be asynchronous, so that the two PAL signals need not be locked to one another.

### 3.3. Video error-correction system

With p.c.m.-coded video signals, transmission errors cause small points of enhanced or reduced brightness to appear on the picture display. D.P.C.M.-coded signals are more seriously impaired by errors since the effect of a single error is to cause a streak across the received picture from the point at which the error occurred to the right-hand side of the display where the prediction is reset. H.D.P.C.M. coding is more resistant to errors since the error-streaks do not often extend to the right-hand side of the display but are stopped where the coding mode changes from d.p.c.m. to p.c.m.

The relative susceptibilities to transmission errors of these three forms of coding is indicated by the random error probability for a "very-slight" subjective impairment, i.e. midway between "imperceptible" and "just perceptible",[3] this probability being $3.10^{-8}$ for p.c.m., $3.10^{-9}$ for d.p.c.m. and $1.10^{-8}$ for h.d.p.c.m.

P.C.M. video signals can be effectively protected against transmission errors by relatively simple concealment techniques in which, for example, an erroneous sample is replaced by a previous correctly-received sample. Such simple concealment techniques are unsatisfactory for d.p.c.m. and h.d.p.c.m. signals and error correction must be used to achieve effective error protection.[4]

The video error-correction system in the BBC equipment employed a Wyner-Ash (16,15)* convolutional code,[4,5] with six units operating independently on each bit of the 6-bit words. This code was applied to video signals only and increased the equivalent serial bit rate for one basic video signal from 53·2 Mbit/s to 56·8 Mbit/s. Because of the interleaving of the six error-correctors per channel, and the subsequent bit-interleaving of the two channels, the error corrector could cope with a burst of up to 12 successive errors in the received 120 Mbit/s bit stream. This ability to deal with short error bursts is an important feature since error-extension** occurs in the transcoding and also (where scrambling is used) in the descrambling required to recover the original binary-coded data signal from the line-transmission signal. Parity framing of the error corrector in the receiver was achieved automatically by circuits which adjusted the framing to minimise the apparent numbers of errors corrected. An optional alternative parity framing method using direct signalling was available by using other bits in the frame structure as described in Section 3.5.

The effective performance of the error corrector for random errors is such that the effective output error-probability is approximately a hundred times the square of the input error-probability. Thus for an input random error probability of $10^{-5}$ the (effective) output error probability is $10^{-8}$ corresponding to a "very slight" impairment for an h.d.p.c.m. signal.

### 3.4. Sound coding

As shown in Fig. 1 each 60 Mbit/s 'package' includes a 2048 kbit/s channel. For the field trials equipment was available designed to multiplex six high-quality sound signals into 2048 kbit/s using "near-instantaneous" digital companding.[6] This is a technique in which a block of 32 10-bit sound-sample words is coded to a quantising accuracy corresponding to 13, 12, 11 or 10 bits per sample depending upon the peak amplitude of the sound signal occurring in the block of 32 samples. In the equipment used in the trials two of the possible six channels were equipped with coders and decoders.

### 3.5. Frame structure

The 120 Mbit/s frame was formed by simple bit-interleaving of two similar, synchronous, 60 Mbit/s signals. It is therefore sufficient to describe the frame structure of the 60 Mbit/s signal. A discussion of the design philosophy of the multiplexer is given in Ref. 7.

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* H.D.P.C.M. denotes a hybrid d.p.c.m./p.c.m. mode where the choice between d.p.c.m. and p.c.m. is dynamically dependent upon the signal.[2]

* This means that one error-checking (parity) bit was added to a sequence of 15 data bits.

** Error extension is the occurrence of more than one error over a short period of time in the binary sequence arising from a single digit error in the line transmission code.

Because the video signal coding produced 6-bit words it was convenient to form up the frame from 6-bit words. The frame length is 1800 bits (30 $\mu$s) formed by 300 6-bit words allocated as follows:

| Word number | Function |
|---|---|
| 0, 1 | Frame Alignment Words 1 and 2 |
| 30, 90, 150 | Justification Control Signal |
| 15, 45, 75, 105, 135, 165, 195, 225, 255, 285 | Sound signal |
| 210 | Justifiable Time Slot, Video |
| 270 | Justifiable Time Slot, Sound |
| The remaining 283 words | Video signal |

Positive justification is used, the Justifiable Time Slots containing real or dummy information as appropriate according to the relation between the input and output bit rates. Two modes of operation were optionally available for the three Justification Control Signal (j.c.s.) words (30, 90 and 150). In one mode the six bits of each of these words were used as follows.

Bit numbers 1 and 5: video j.c.s.
Bit numbers 2 and 6: sound j.c.s.
Bit number 3 : video j.c.s. (complemented)
Bit number 4 : sound j.c.s. (complemented)

In this mode the j.c.s. words are heavily redundant; in the alternative mode only 3 bits (i.e. 1 bit in each of 3 words) were used for justification signalling, thus leaving a total of 12 bits, i.e. 4 bits in 3 words per frame for auxiliary signalling purposes. One bit in each of these words was then used to provide the optional direct-signalling parity framing for the video error corrector decoder as mentioned in Section 3.3.

The word rate of 10 Mword/s is sufficiently slow for all the necessary operations to be conveniently carried out in six parallel streams, using relatively inexpensive slow-speed logic (TTL). These are then serialised to produce a 60 Mbit/s serial stream, requiring a minimum of high-speed logic. Interleaving of two 60 Mbit/s signals also requires very little high-speed logic.

The intrinsic digital frame-alignment time of the demultiplexer does not exceed about 500 $\mu$s even in the presence of a random error rate as high as 1 in $10^2$. However additional time is required for phase-locked-loop clock pulse regenerators to stabilise in the BBC equipment. An error-free output is obtained after about 0·15 secs. and a fully time-stable output after about 0·3 secs.

## 4. The transmission tests

For the April 1975 pilot trial only the Portsmouth/Guildford section of the Experimental Line System was used; the main object was to check that the HDB-3 interfacing between BBC and PO equipments was satisfactory and to check that no unexpected difficulties arose which might impede the main trial.

In general there were three main aspects of interest in the trials — interfacing, timing jitter and bit errors. The latter two items represent the main sources of impairment which can arise in a digital transmission system. The three aspects are discussed separately below.

### 4.1. Interfacing

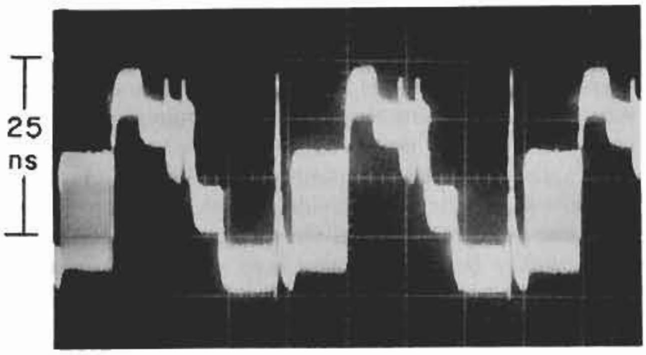
The BBC HDB-3 coder at first failed to drive the system because the output level was about 15%-20% higher than that specified for interface signals. Failure occurred for this rather surprisingly small excess level because the automatic equaliser in the Post Office HDB-3 decoder was designed to compensate for the effects of various cable lengths, rather than for an HDB-3 signal which is outside the specified tolerance of ±10% on the nominal peak-to-peak voltage. Minor adjustment of the BBC coder for correct output level cleared the trouble.

### 4.2. Jitter observations

In general, jitter is not a problem to operation of the BBC equipment provided that the amplitude is not so great that digital errors occur. This follows since effective jitter reduction is introduced by the phase-locked crystal-controlled clock-pulse oscillators which are essential in demultiplexing. Nevertheless jitter characteristics are an aspect of digital system performance which is of considerable importance in overall system design. For this reason comprehensive jitter measurements were made by the Post Office and system Manufacturers, using the BBC signals and a technique in which jitter is detected by comparing clock pulses derived from the output of the line system with stable reference clock pulses which by-passed the line system.

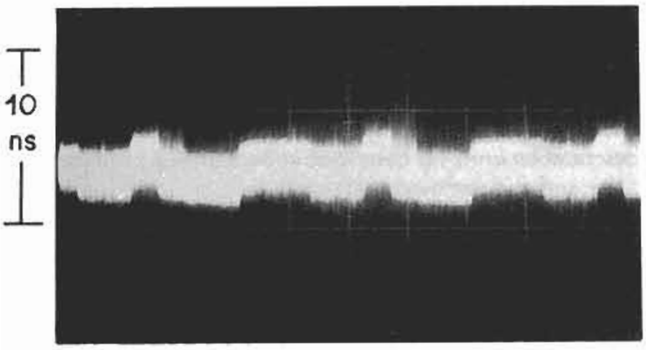
Jitter measurements were made with various conditions of the transmission system i.e. scrambling, no scrambling, jitter reducer units in, jitter reducer units out, and for various types of video coding, i.e. p.c.m., d.p.c.m. and h.d.p.c.m. Also the effect of different video analogue signals was investigated since these were found to affect the jitter performance under certain conditions. Space does not permit the presentation of the results of the many measurements made; instead the main facts which emerged will be given. These are as follows:

(a) The highest amplitudes of jitter occurred with p.c.m. video signals and with video-test waveforms fed to the coder. For example, with no scrambler or



without scrambler 33ns p-p

*(a)*



with 9-stage scrambler 4.3ns p-p

*(b)*

***Fig. 2 - Jitter amplitude displays***

6-bit PCM horizontal 5-step grey-scale video-signal in channel A of multiplex

jitter reducer in the transmission system the jitter was about 30 ns p-p for a 5-step horizontal grey scale video-test waveform. The marked pattern-dependence of the jitter for this signal is evident in the jitter-amplitude display shown in Fig. 2(a) in which the field-rate waveform of the 5-step grey scale is clearly discernible.

(b) Changing the video coding to d.p.c.m. or h.d.p.c.m. tended to reduce the jitter amplitude. This might be expected since, with efficient prediction in a d.p.c.m. system, the transmitted difference values tend to be small, and to contain a greater random element than p.c.m. signals.

(c) Scrambling and jitter-reducer units are both useful in controlling jitter. Insertion of scrambling was found to reduce r.m.s ~~peak-to-peak~~ jitter by a factor ranging from 1·5 to 3·0. 6? A jitter reducer reduced jitter by a factor of about 30. Although a scrambler is therefore less effective than a jitter reducer in reducing jitter it reduces pattern-dependent effects which might result in serious impairments due to the build-up of excessive jitter (see Section 4.3.). Fig. 2(b) shows the effect of a 9-stage scrambler in breaking up and reducing the strongly pattern-dependent jitter visible in Fig. 2(a).

(d) Jitter spectrum plots showed that, without scrambling, pronounced spectral components were present relating to the line-frequency content of the two video signals encoded in the digit stream. In one case, two somewhat different characteristics were possible apparently deriving from different start-up conditions of the line-transmission ternary coding in relation to the two bit-interleaved 60 Mbit/s streams comprising the input 120 Mbit/s signal. With scrambling, no pronounced spectral components were present and the overall shape of the spectrum plot accorded with that predictable for a pseudo-random signal from a knowledge of the number of regenerative repeaters in the path and the effective Q of the regenerator time-extraction tank circuits.[8]

### 4.3. Error performance

#### 4.3.1. Error-monitoring facilities

With the BBC equipment in the main field trial it was possible to observe and monitor errors in three ways:

(a) by detecting departures from HDB-3 coding rules in the HDB-3 receiver;
(b) from the activity of the A-channel video error corrector;
(c) by observation of the received television picture.

Method (a) could only reveal errors occurring in the HDB-3 interfacing system at the receiving end since any errors occurring on the line transmission signal or earlier would be undetectable in the re-coded HDB-3 signal.

Method (b) detected errors which had occurred in any part of the transmission system and which were in the A-channel video signal. For a random error distribution not exceeding a rate of about 5 in $10^3$ it was possible to measure the error rate to an accuracy of 10% by means of a counter. For a pattern-dependent error distribution the error rate indication would almost certainly be inaccurate and below the true rate because the spacing between errors would be less than the constraint length of the Wyner-Ash error correction code.

Method (c) was valuable in showing whether errors were approximately random or pattern-dependent. For random errors experienced observers could deduce the error rate to within a power of 10 in accuracy in the range 1 in $10^6$ to 1 in $10^3$.

The Post Office terminal equipment also incorporates means for detecting errors and for indicating the error rate. The technique used for "in-traffic" error rate monitoring is to check the disparity (i.e. the running digital sum) of the received ternary signal. An error alters the cumulative sum by one state and when the transmitted sum reaches one of its limits the error causes the limit of the received signal to be exceeded. Thus errors are not detected immediately but later, provided the digital sum reaches its limit before another error occurs. Accurate monitoring of a random error rate up to about 1 in $10^4$ is possible using this technique, and the terminals were equipped with indicator lights for error rates of 1 in $10^4$, $10^5$, $10^6$ and $10^7$ in conjunction with continuously-running chart recorders for long-term observations.

Checking of BBC error-correction and error-rate monitoring systems was possible by inserting random errors at a known rate into the 120 Mbit/s binary signal. Special units were constructed for this purpose and are included in Fig. 1. No facilities were available at the field trials for introducing controlled errors into the line-transmission signal.

### 4.3.2. Error observations

In the pilot tests on the Guildford loop no system errors occurred when transmitting the single p.c.m.-coded signal. "Artificial" errors were therefore induced in two ways.

(1) By manual pulling of the control voltage in the automatic equaliser of the final 4B3T regenerator unit. By this means the amplified pulse shape could be distorted so as to reduce the "eye" size at the regenerator, thus degrading the regeneration process.

(2) By attenuating the input signal from the line system to the final 4B3T regenerator.

The effects of these induced errors were observed during the pilot tests on a colour television display using either a Test Card 'F' picture or a vertical colour bar test signal. With no scrambler in use on the line-system the dot distribution due to errors induced by both methods tended to be related to the picture content and, for the colour bar signal particularly, coloured single line streaks were evident. These streaks were caused by incorrect R-Y switching of the reference subcarrier in the PAL decoder which derived its PAL switching waveform from line synchronising pulses. With a scrambler in use errors induced by method (1) were still somewhat dependent upon picture content whilst errors induced by method (2) appeared to be random.

In the main field trial on the Guildford loop no test signals caused any system errors to occur under normal conditions. Errors were therefore artificially induced again as in the pilot tests using method (2) given above. On this occasion however, tests were possible only with scrambling in use. At an indicated error rate of about 1 in $10^5$ the errors so induced were clearly not random (as shown by the picture monitor) even with an h.d.p.c.m.-coded video signal and tended to be concentrated in the region of the sync-edges of the video waveform. It was also apparent that the video error corrector was almost completely ineffective in dealing with these picture-dependent errors, presumably because the spacing between errors was less than the constraint length of the Wyner-Ash error correctors.

In the case of the Southampton loop it was not possible to induce "artificial" errors by method (2) since there was no convenient access to the ternary line-transmission signal after the repeater power-feeding filter. However, some system errors occurred when using this loop (which did not contain a scrambler), probably as a result of excessive jitter, when certain video signals were transmitted. The video signal which caused most errors was a 6-bit p.c.m. signal with a 5-step horizontal grey scale test waveform. The indicated error rate with this signal depended upon the start-up phasing of the binary-to-ternary translator and was either about 1 in $10^5$ or 1 in $10^9$. The error rate also varied cyclically between about 1 in $10^5$ and 1 in $10^7$ (worst phasing of binary-to-ternary) when the B-channel video signal was present, presumably due to the continuous change in relative timing of the two video waveforms with their independent synchronising pulses and colour subcarriers. The errors were pattern-dependent and appeared to be associated with the line-blanking intervals of the video signals; because of the pattern-dependence, the video error-corrector was largely ineffective for the reason given above. Finally the insertion of external scrambler and descrambler units (as described in Section 4.2.) reduced the jitter and also removed the errors.

### 4.4. Signal quality appraisal

Except for the conditions when errors were present, observations of picture and sound quality showed, as might be expected, that this was unchanged when the digital signal passed through the line system compared to the 'by-pass' (back-to-back) connection of the BBC equipment. This applied for both line sections individually and for the two sections connected in cascade.

### 4.5. 2048 kbit/s sound multiplexing test

For most tests the BBC 2048 kbit/s signal was fed, in binary-data-plus-clock form, into the BBC multiplexing equipment as shown in Fig. 1. However, brief additional tests were made in which the 2048 kbit/s signal was fed in HDB-3 form into Post Office multiplexing equipment. This first multiplexed four 2048 kbit/s signals to produce a 8448 kbit/s stream; fourteen 8448 kbit/s signals were then multiplexed together to produce a 120 Mbit/s signal. These additional tests were entirely satisfactory, no difficulties being apparent with interfacing, jitter or errors.

## 5. Conclusions

The joint BBC/PO trials over a Post Office experimental 120 Mbit/s digital line system covered three main aspects — interfacing, jitter and error observations — encountered when using the BBC Research Department experimental television and sound digital multiplex equipment at the terminals.

No serious problems arose with interfacing although the importance of keeping within fairly close tolerances on the interface voltage levels was evident.

Observations of jitter introduced by the transmission systems showed that this was related to the analogue video waveform and could be as high as 30 ns peak-to-peak when no scrambler or jitter reducer units were included. However, it was confirmed that such transmission jitter is not likely to be a problem with BBC equipment because clock-pulse regeneration units, essential in the demultiplexing process, act as effective jitter reducers. It was found however that, unless scrambling is employed, excessive jitter can result in transmission errors with certain video signals. Although this problem may not be fundamental, it is indicative of practical difficulties likely to arise, particularly on long circuits. It is concluded therefore that scrambling is highly desirable to ensure that transmission systems are virtually transparent, i.e. bit-sequence independent. Whether scramblers should be part of the transmission terminal equipment is debatable, however, since error-extension with the types of scrambler used hitherto may reduce the effectiveness of error protection. Arrangements that can give scrambling without error extension would merit further study.

The error rate of the line transmission systems is normally almost zero. Methods used for inducing "artificial" errors gave an error distribution which was not random but tended to be pattern-dependent, i.e. related to the video analogue signal even when scrambling was in use. In this situation the video error-corrector incorporated in the multiplex equipment and designed to deal with random errors, was almost totally ineffective because the spacing between errors was less than the constraint length of the Wyner-Ash coders. An effective error corrector for such errors would require a large increase in the bit-rate for the protected video channel and is therefore not likely to be an economic proposition. This should be borne in mind when designing coding systems since some of the genuine errors which result from a failing line transmission system might well take the pattern-dependent form of the artificially induced errors.

In general the field trials were very successful and provided interesting information to all who participated. In particular the trials emphasised the value of tests with real signals, i.e. signals representative of the form that digital video and digital sound for broadcasting may take, rather than tests with fixed patterns and pseudo-random sequences.

## 6. Acknowledgements

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## 7. References

1. MOORE, T.A. 1973. Digital transmission codes: properties of HDB-3 and related ternary codes with reference to broadcast signal distribution. The Radio and Electronic Engineer, 1973, Vol. 44, No. 8, pp 421-427.

2. DEVEREUX, V.G. *and* PHILLIPS, G.J. 1974. Bit-rate reduction of digital video signals using differential p.c.m. techniques. International Broadcasting Convention 1974, IEE Conference Publication No. 119, pp 83-89.

3. RATLIFF, P.A. 1974. Digital video: subjective assessment of an experimental Wyner-Ash error corrector. BBC Research Department Report No. 1974/41.

4. STOTT, J.H., OLIPHANT, A. *and* OSBORNE, D.W. 1974. Digital video: error-correcting codes and a practical study of a Wyner-Ash error-corrector. BBC Research Department Report No. 1974/40.

5. WYNER, A.D. *and* ASH, R.B. 1963, Analysis of recurrent codes. IEEE Trans. IT-9, No. 3, July 1963, pp 143-156.

6. CROLL, M.G., OSBORNE, D.W. *and* SPICER, C.R. 1974. Digital sound signals; the present BBC distribution system and a proposal for bit-rate reduction by digital companding. International Broadcasting Convention 1974, IEE Conference Publication No. 119, pp 90-95.

7. BBC Research Department Report in course of preparation.

8. BYRNE, C.J., KARAFIN, B.J. *and* ROBINSON Jr. D.B. 1963. Systematic jitter in a chain of digital regenerators. Bell System Technical Journal, 1963, November, Vol. XLII, No. 6, pp 2679-2714.

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